REMARKS

Status of the Claims

Upon entry of the amendment above, claims 16-72 will be pending, claims 16, 67, and 68 being independent.

Summary of the Office Action

Claim 16-57 are rejected under 35 USC §103(a) as being unpatentable over TAKAMOTO et al. (U.S. Patent No. 5,665,295, hereinafter "TAKAMOTO").

Response to the Office Action

A. TAKAMOTO Fails to Disclose a Fiber Composite Core

In rejected independent claim 16, Applicants call for, *inter alia*, a sandwich structure that comprises a fiber composite core and fiber composite outer layers, the fiber composite outer layers comprising higher-strength fibers than the fibers of the composite core.

TAKAMOTO fails to disclose a fiber composite core of a sandwich structure.

Accordingly, Applicants submit that the rejection should be withdrawn at least for this reason.

The first sentence of the statements in support of the rejection refers to column 1, through line 16. This provides a short summary of TAKAMOTO's invention.

In that summary, TAKAMOTO says nothing about a fiber composite core.

Instead, TAKAMOTO refers, in the aforementioned summary, to "a core portion of a porous resin layer having numerous air foams ...."

The core layer of TAKAMOTO's molded composite article is a resin with embedded *particles* (*i.e.*, not *fibers*), some of which are compressible. In the detailed description of TAKAMOTO's specification, such as at column 5, lines 60-65, the core is referred to as being

composed of "light-weight filler *particles*, having an average particle diameter in the range of 0.01 to 2.0 mm.

Particles are not fibers, particularly in the context of the art of composite materials, to those of ordinary skill in that art. In support of this contention, Applicants have attached the title page, copyright page, and pages 10-11 and 27-28 from Volume 1, entitled "Composites," of *Engineered Materials Handbook*, ASM International, 1987.

On page 10 thereof, "fiber" is defined as "a general term for a filament with a finite length that is at least 100 times its diameter ...."

On page 27, a chapter entitled "Introduction to Composites" explains (see paragraphs 3-5 in the leftmost column) the differences between *fiber*-reinforced composites and *particle*-reinforced composites, some of the latter of which are described "filled" systems. In the fourth paragraph, examples of "particles" are given as spheres, rods, flakes, and other shapes.

As mentioned above, TAKAMOTO itself describes the core of the therein disclosed composite as being composed of light-weight *filler particles* and the particles are referred to as having a diameter, *i.e.*, spherical.

The aforementioned *Engineered Materials Handbook* explains (*i.e.*, in the fourth paragraph) that some "filled" systems can be said to reinforce the matrix material (resin, *e.g.*), although other such systems do not, such as those which employ materials for fire resistance, control of shrinkage, or increased thermal conductivity.

While it appears clear that the core layer of the TAKAMOTO composite is a "filled" system, and while it is quite questionable whether it can be considered to be a particle-reinforced composite, *it is clearly not a fiber-reinforced composite*, particularly as described by TAKAMOTO in the detailed description, such as beginning at column 5, line 66.

In summary, therefore, Applicants invention has been disclosed and claimed as a sandwich that comprises two higher-strength fiber composite outer layers an a lower-strength fiber composite core. By contrast, TAKAMOTO discloses a composite molded article that includes two surface layer portions of fiber-reinforced resin and a resin core embedded with particles. The respective cores are different at least inasmuch as TAKAMOTO shows no concern for employing a core that includes lower-strength fibers.

In addition to Applicants' claimed invention possessing at least this difference from that which is disclosed by TAKAMOTO, Applicants submit that one skilled in the art would not have been lead by TAKAMOTO, or others, to have replaced the filler particles of the composite there disclosed with fibers. Accordingly, it would not have been obvious to have modified TAKAMOTO's composite in a way that would have resulted in Applicants' invention.

In this regard, one can see from column 3, lines 5-9 of TAKAMOTO that an object of TAKAMOTO's invention was to "provide a process for the production of a composite molded article having a foamed core-sandwich structure, which process is free of any problem caused by the above prior art processes."

And the "above prior art processes" referenced by TAKAMOTO are those of the three patent documents referenced in the "Prior Art" section of TAKAMOTO's specification, all of which utilize particles in the cores of their composites, such as hollow spherical filler particles (see column 1, lines 53-54).

TAKAMOTO's disclosure, then, is quite clearly directed to particle cores, not fiber composite cores. No suggestion is provided by TAKAMOTO to those skilled in the art of composites to consider fiber composite cores.

Further, Applicants' claimed invention provides unexpected results even if one were to find it necessary in concluding their invention to have been non-obvious. For example, as

mentioned in paragraph 0014 of their specification, Applicants have created a sandwich composite (*i.e.*, "sandwich" as understood by those skilled in the art of composites) in which the core of the sandwich can include reinforcing fibers while not adversely affecting the mechanical properties of the composite.

This contrasts with known composites, such as those described in Applicants' background section of their specification, which include those having rigidities that are too substantial to be used for certain products such as sports equipment and boots, where a certain amount of longitudinal deformability would be advantageous, as Applicants explain in paragraph 0007 of their specification.

In addition to the foregoing comments which are directed to the rejection in its entirety, Applicants respectfully take issue with certain comments in the rejection which are directed to particular ones of the dependent claims.

In this regard, the rejection includes the comment "Concerning claims 17, 18, 20-22, the cited reference teaches the claimed dimension in col. 2, lines 17-27."

In Applicants' claim 17 reference is had to the total thickness of the claimed laminate (less than or equal to 3 mm) and claims 18, 20-22 refer to various dimensions of the *core*.

Regarding the thickness of claim 17, column 2, lines 17-27 of TAKAMOTO (which describes certain prior art) describes *a total thickness of a molded article* to be "5.8 mm" (which, Applicants also submit, is substantially outside the range of claim 17).

Also, column 2, lines 17-27 do not appear to relate at all to the subject matter of Applicants' claims 18, 20-22.

Similarly, the rejection includes the comment "Concerning claims 23-31, 34-41, the cited reference teaches the claimed limitations in col. 4, lines 32-55."

Applicants' claims 23-31 are directed to specific characteristics of the *core*. By contrast, column 4, lines 32-55 of TAKAMOTO appears to be directed to a description of the reinforcing fibrous sheets.

Lastly in this regard, the rejection makes reference to a number of passages of TAKAMOTO as allegedly disclosing the subject matter of Applicants' claims 51-53 (which refer to the core comprising "a plurality of superimposed plies of composite material", etc.).

TAKAMOTO does not disclose a multi-ply core.

In spite of the foregoing arguments in support of their position that the rejection based upon TAKAMOTO should be withdrawn, Applicants have reviewed the entire disclosure of TAKAMOTO and further note the following, although Applicants submit that TAKAMOTO fails to teach or suggest their invention.

Column 8, lines 5-29 and the corresponding descriptions of Examples 11 and 12 (starting in column 24) of TAKAMOTO explain that the composite core can be reinforced *locally* by a diverse type of reinforcement.

It is important to understand that such reinforcements are in fact "self-standing" composite structures embedded within the resin-particles compound.

Therefore, this proposal of a reinforced core renders the core very heterogeneous. Even though a composite, by definition, is a heterogeneous material, here the core becomes heterogeneous on a macroscopic level. So, even though TAKAMOTO indicates that some materials are usable as reinforcements, such as polyester, polyamide, and cellulose (column 8, line 18), which are also suitable as core fibers in Applicants' invention, TAKAMOTO does not teach the use of fibers of lesser mechanical strength than those of the skins (*i.e.*, outer layers). Indeed, in Example 11, the reinforced ribs are made with glass fiber powder (*i.e.*, particles ---

not fibers) and, in Example 12, they are made of 6 mm diameter braided glass-fiber strands. In both cases, the material used as reinforcement for the core is glass, the same as that for the skin layers.

B. Withdrawal of Finality of Office Action

Applicants kindly request that, unless the instant application were to be allowed, the finality of the Office action to which reply is being made herewith be withdrawn as being premature.

In the first Office action no rejection based upon prior art was advanced; the only rejection was for alleged indefiniteness of the claims.

In the ***final*** Office action, the indefiniteness rejection has been withdrawn but a ***new rejection*** has been advanced for obviousness. In Section 19 of the final Office action, the finality thereof is rationalized with the form paragraph which includes the statement that "Applicant's amendment necessitated the ground(s) of rejection ...."

Applicants respectfully submit that if USPTO guidelines (*i.e.*, according to the examiner's Manual of Patenting Examining Procedure (such as MPEP §706.07(a))) were to be respected, the Office action should not have been made final.

In this regard, Applicants note that original claim 1 and new independent claim 16 are substantial duplicates, claim 16 having been rewritten primarily for the purpose of addressing the lack of antecedent basis for the expression "the fibers of the core" in line 4 of original claim 1.

Even if some or all of the original dependent (*i.e.*, claims 2-15) claims were to have presented issues of indefiniteness, Applicants submit that "the fibers of the core" in claim 1 should not have obscured the metes and bounds of claim 1. That is, it should have been clearly understood that the core of the claimed sandwich structure includes fibers.

Therefore, the meaning of original claim 1 should have been found to be substantially the same as that of new claim 16, despite any allegation of indefiniteness.

In view of the foregoing, Applicants request reconsideration of the finality of the Office action and that such finality be withdrawn as being premature. See, *e.g.*, MPEP §706.07(d).

Further, in view of the running of the reply period set in the final Office action, Applicants request that their request for reconsideration of the finality of the Office action be construed as a petition under 37 CFR §1.181 in the event their request for reconsideration were to be denied.

C. Withdrawal of Finality of Office Action

Applicants have presented new claims 67-72 (of which claims 67 and 68 are independent) for the Examiner's consideration.

Both of independent claims 67 and 68 make use of the transition phrase "consisting essentially of" in connection with the composition of the core of their claimed sandwich laminate structure. Specifically, in claim 67 Applicants recite "a core *consisting essentially of* a fiber-reinforced composite having a predeterminate mechanical strength" and, in claim 68, Applicants recite "a core *consisting essentially of* a composite, the composite comprising a polymer resin matrix reinforced with fibers, the fibers of the composite *consisting essentially of* fibers having a mechanical strength no greater than a predeterminate magnitude."

New claims 69-72 depend from independent claim 68 and give specific recitations of the strength of the fibers of the core.

In addition, the reasons for allowance of the new claims include at least the reasons given above in connection with the previously presented claims.

SUMMARY

Allowance of the instant application is kindly requested in view of the amendment and explanation presented above, which are believed to address and resolve issues raised in

connection with the sole ground of rejection. Accordingly, reconsideration and withdrawal of the rejection is requested.

A check is enclosed for payment of a claim fee. No additional fee is believed to be due at this time. However, the Commissioner is authorized to charge any fee required for acceptance of this reply as timely and complete to Deposit Account No. 19-0089.

Further, although no extension of time is believed to be necessary at this time, if it were to be found that an extension of time were necessary to render this reply timely and/or complete, Applicants request an extension of time under 37 CFR §1.136(a) in the necessary increment(s) of month(s) to render this reply timely and/or complete and the Commissioner is authorized to charge any necessary extension of time fee under 37 CFR §1.17 to Deposit Account No. 19-0089.

Any comments or questions concerning this application can be directed to the undersigned at the telephone or fax number given below.

Respectfully submitted,
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Attachment: *Engineered Materials Handbook*, ASM International, 1987, pp. 10-11 and 27-28, Volume 1: "Composites"

EXEMPLAIRE
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APRÈS LECTURE
SVP RETOUR RAPIDE

Volume 1 ENGINEERED MATERIALS HANDBOOK™

COMPOSITES

ASM International ASM INTERNATIONAL™

First printing, November 1987
Second printing, May 1988

Engineered Materials Handbook is a collective effort involving hundreds of technical specialists. It brings together in one book a wealth of information from world-wide sources to help scientists, engineers, and technicians solve current and long-range problems.

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elastic deformation. The part of the total strain in a stressed body that disappears upon removal of the stress.

elasticity. That property of materials by virtue of which they tend to recover their original size and shape after removal of a force causing deformation. See also *viscoelasticity*.

elastic limit. The greatest stress a material is capable of sustaining without permanent strain remaining after the complete release of the stress. A material is said to have passed its elastic limit when the load is sufficient to initiate plastic, or nonrecoverable, deformation.

elastic recovery. The fraction of a given deformation that behaves elastically. A perfectly elastic material has an elastic recovery of 1; a perfectly plastic material has an elastic recovery of 0.

elastomer. A material that substantially recovers its original shape and size at room temperature after removal of a deforming force.

elastomeric tooling. A tooling system that uses the thermal expansion of rubber materials to form composite parts during cure.

electrical dissipation factor. The ratio of the power loss in a dielectric material to the total power transmitted through it; thus, the imperfection of the dielectric. Equal to the tangent of the loss angle.

electroformed molds. A mold made by electroplating metal on the reverse pattern of the cavity. Molten steel may then be sprayed on the back of the mold to increase its strength.

elongation. Deformation caused by stretching. The fractional increase in length of a material stressed in tension. (When expressed as percentage of the original gage length, it is called percentage elongation.)

elongation at break. Elongation recorded at the moment of rupture of the specimen, often expressed as a percentage of the original length.

encapsulation. The enclosure of an item in plastic. Sometimes used specifically in reference to the enclosure of capacitors or circuit board modules.

end. A strand of roving consisting of a given number of filaments gathered together. The group of filaments is considered an "end" or strand before twisting, a "yarn" after twist has been applied. An individual warp yarn, thread, fiber, or roving.

end count. An exact number of ends supplied on a ball of roving.

endurance limit. See *fatigue limit*.

environment. The aggregate of all conditions (such as contamination, temperature, humidity, radiation, magnetic and electric fields, shock, and vibration) that externally influence the performance of an item.

environmental stress cracking (ESC). The susceptibility of a thermoplastic resin to crack or craze when in the presence of surface active agents or other environments.

epichlorohydrin. The basic epoxidizing resin intermediate in the production of epoxy resins. It contains an epoxy group and is highly reactive with polyhydric phenols such as bisphenol A.

epoxide. Compound containing the oxirane structure, a three-member ring containing two carbon atoms and one oxygen atom. The most important members are ethylene oxide and propylene oxide.

epoxy plastic. A polymerizable thermoset polymer containing one or more epoxide groups and curable by reaction with amines, alcohols, phenols, carboxylic acids, acid anhydrides, and mercaptans. An important matrix resin in composites and structural adhesive.

equator. In filament winding, the line in a pressure vessel described by the junction of the cylindrical portion and the end dome. Also called tangent line or point.

ESC. See *environmental stress cracking*.

even tension. The process whereby each end of roving is kept in the same degree of tension as the other ends making up that ball of roving. See also *catenary*.

exotherm. The liberation or evolution of heat during the curing of a plastic product.

extend. To add fillers or low-cost materials in an economy producing endeavor. To add inert materials to improve void-filling characteristics and reduce crazing.

extenders. Low-cost materials used to dilute or extend high-cost resins without extensive lessening of properties. See also *filler*.

extensibility. The ability of a material to extend or elongate upon application of sufficient force, expressed as percent of the original length.

extensional-bending coupling. A property of certain classes of laminates that exhibit bending curvatures when subjected to extensional loading.

extensional-shear coupling. A property of certain classes of laminates that exhibit shear strains when subjected to extensional loading.

extensometer. A mechanical or optical device for measuring linear strain due to mechanical stress.

F

fabricating (fabrication). The manufacture of products from molded parts, rods, tubes, sheeting, extrusions, or other form by appropriate operations, such as punching, cutting, drilling, and tapping. Fabrication includes fastening parts together or to other parts by mechanical devices, adhesives, heat sealing, welding, or other means.

fabric fill face. That side of the woven fabric where the greatest number of the yarns are perpendicular to the selvage.

fabric, nonwoven. See *nonwoven fabric*.

fabric prepreg batch. Prepreg containing fabric from one fabric batch, impregnated with one batch of resin in one continuous operation.

fabric warp face. That side of the woven fabric where the greatest number of the yarns are parallel to the selvage.

fabric, woven. See *woven fabric*.

fairing. A member or structure, the primary function of which is to streamline the flow of a fluid by producing a smooth outline and to reduce drag, as in aircraft frames and boat hulls.

fatigue. The failure or decay of mechanical properties after repeated applications of stress. Fatigue tests give information on the ability of a material to resist the development of cracks, which eventually bring about failure as a result of a large number of cycles.

fatigue life. The number of cycles of deformation required to bring about failures of the test specimen under a given set of oscillating conditions (stresses or strains).

fatigue limit. The stress level below which a material can be stressed cyclically for an infinite number of times without failure.

fatigue ratio. The ratio of fatigue strength to tensile strength. Mean stress and alternating stress must be stated.

fatigue strength. The maximum cyclical stress a material can withstand for a given number of cycles before failure occurs. The residual strength after being subjected to fatigue.

faying surface. The surfaces of materials in contact with each other and joined or about to be joined together.

felt. A fibrous material made up of interlocked fibers by mechanical or chemical action, moisture, or heat. Made from fibers such as asbestos, cotton, glass, and so forth. See also *batt*.

fiber. A general term used to refer to filamentary materials. Often, fiber is used synonymously with filament. It is a general term for a filament with a finite length that is at least 100 times its diameter, which is typically 0.10 to 0.13 mm (0.004 to 0.005 in.). In most cases it is prepared by drawing from a molten bath, spinning, or deposition on a substrate. A whisker, on the other hand, is

a short single-crystal fiber or filament made from a wide variety of materials, with diameters ranging from 1 to 25 μm (40 to 1400 μin.) and aspect ratios (a measure of length) between 100 and 15 000. Fibers can be continuous or specific short lengths (discontinuous), normally no less than 3.2 mm (1/8 in.).

fiber content. The amount of fiber present in a composite. This is usually expressed as a percentage volume fraction or weight fraction of the composite.

fiber count. The number of fibers per unit width of ply present in a specified section of a composite.

fiber diameter. The measurement (expressed in hundred thousandths) of the diameter of individual filaments.

fiber direction. The orientation or alignment of the longitudinal axis of the fiber with respect to a stated reference axis.

fiberglass. An individual filament made by drawing molten glass. A continuous filament is a glass fiber of great or indefinite length. A staple fiber is a glass fiber of relatively short length, generally less than 430 mm (17 in.), the length related to the forming or spinning process used.

fiberglass reinforcement. Major material used to reinforce plastic. Available as mat, roving, fabric, and so forth, it is incorporated into both thermosets and thermoplastics.

fiber pattern. Visible fibers on the surface of laminates or molding. The thread size and weave of glass cloth.

fiber-reinforced plastic (FRP). A general term for a composite that is reinforced with cloth, mat, strands, or any other fiber form.

fiber show. Strands or bundles of fibers that are not covered by plastic and that are at or above the surface of a composite.

fiber wash. Splaying out of woven or nonwoven fibers from the general reinforcement direction. Fibers are carried along with bleeding resin during cure.

filament. The smallest unit of a fibrous material. The basic units formed during drawing and spinning, which are gathered into strands of fiber for use in composites. Filaments usually are of extreme length and very small diameter, usually less than 25 μm (1 mil). Normally filaments are not used individually. Some textile filaments can function as a yarn when they are of sufficient strength and flexibility.

filament winding. A process for fabricating a composite structure in which continuous reinforcements (filament, wire, yarn, tape, or other), either previously impregnated with a matrix material or impregnated during the winding, are placed over a rotating and removable form or mandrel in a prescribed way to meet certain stress conditions. Generally the shape is a surface of revolution and may or may not include end closures. When the required number of layers is applied, the wound form is cured and the mandrel removed.

fill. Yarn oriented at right angles to the warp in a woven fabric.

filler. A relatively inert substance added to a material to alter its physical, mechanical, thermal, electrical, and other properties or to lower cost or density. Sometimes the term is used specifically to mean particulate additives. See also *inert filler*.

fillet. A rounded filling or adhesive that fills the corner or angle where two adherends are joined.

filling yarn. The transverse threads or fibers in a woven fabric. Those fibers running perpendicular to the warp. Also called weft.

film adhesive. A synthetic resin adhesive, usually of the thermosetting type, in the form of a thin, dry film of resin with or without a paper or glass carrier.

finish. A mixture of materials for treating glass or other fibers. It contains a coupling agent to improve the bond of resin to the fiber, and usually includes a lubricant to prevent abrasion, as well as a binder to promote strand integrity. With graphite or other filaments, it may perform any or all of the above functions.

first-order transition. A change of state associated with crystallization or melting in a polymer.

flame resistance. Ability of a material to extinguish flame once the source of heat is removed. See also *self-extinguishing resin*.

flame retardants. Certain chemicals that are used to reduce or eliminate the tendency of a resin to burn.

flammability. Measure of the extent to which a material will support combustion.

flash. That portion of the charge which flows from or is extruded from the mold cavity during the molding. Extra plastic attached to a molding along the parting line, which must be removed before the part is considered finished.

flexibilizer. An additive that makes a finished plastic more flexible or tough. See also *plasticizer*.

flexible molds. Molds made of rubber or elastomeric plastics, used for casting plastics. They can be stretched to remove cured pieces with undercuts.

flexural modulus. The ratio, within the elastic limit, of the applied stress on a test specimen in flexure to the corresponding strain in the outermost fibers of the specimen.

flexural strength. The maximum stress that can be borne by the surface fibers in a beam in bending. The flexural strength is the unit resistance to the maximum load before failure by bending, usually expressed in force per unit area.

flow. The movement of resin under pressure, allowing it to fill all parts of a mold. The gradual but continuous distortion of a material under continued load, usually at high temperatures; also called creep.

flow line. A mark on a molded piece made by the meeting of two flow fronts during molding. Also called striae, weld mark, or weld line.

flow marks. Wavy surface appearance of an object molded from thermoplastic resins, caused by improper flow of the resin into the mold.

fluted core. An integrally woven reinforcement material consisting of ribs between two skins in a unitized sandwich construction.

foamed plastics. Resins in sponge form, flexible or rigid, with cells closed or interconnected and density over a range from that of the solid parent resin to 0.030 g/cm^3. Compressive strength of rigid foams is fair, making them useful as core materials for sandwich constructions. Also, a chemical cellular plastic, the structure of which is produced by gases generated from the chemical interaction of its constituents.

foaming agent. Chemicals added to plastics and rubbers that generate inert gases on heating, causing the resin to assume a cellular structure.

foam-in-place. Refers to the deposition of foams when the foaming machine must be brought to the work that is "in place," as opposed to bringing the work to the foaming machine. Also, foam mixed in a container and poured into a mold, where it rises to fill the cavity.

force. The male half of the mold that enters the cavity, exerting pressure on the resin and causing it to flow. Also called punch.

FP fiber. Polycrystalline alumina fiber (Al_2O_3). A ceramic fiber useful for high-temperature (1370 to 1650 °C, or 2500 to 3000 °F) composites.

fracture. The separation of a body. Defined both as rupture of the surface without complete separation of laminate and as complete separation of a body because of external or internal forces.

fracture stress. The true, normal stress on the minimum cross-sectional area at the beginning of fracture.

fracture toughness. A measure of the damage tolerance of a material containing initial flaws or cracks. Used in aircraft structural design and analysis.

Introduction to Composites

Theodore J. Reinhart, Air Force Wright Aeronautical Laboratories
Linda L. Clements, San Jose State University

A COMPOSITE MATERIAL can be defined as a macroscopic combination of two or more distinct materials, having a recognizable interface between them. However, because composites are usually used for their structural properties, the definition can be restricted to include only those materials that contain a reinforcement (such as fibers or particles) supported by a binder (matrix) material.

Thus, composites typically have a discontinuous fiber or particle phase that is stiffer and stronger than the continuous matrix phase. In order to provide reinforcement, there generally must be a substantial volume fraction (~10% or more) of the discontinuous phase. There are, however, exceptions that may still be considered composites, such as rubber-modified polymers, where the discontinuous phase is more compliant and more ductile than the polymer, resulting in improved toughness.

Composites can be divided into classes in various manners. One simple classification scheme is to separate them according to reinforcement forms—particulate-reinforced, fiber-reinforced, or laminar composites. Fiber-reinforced composites can be further divided into those containing discontinuous or continuous fibers.

A reinforcement is considered to be a "particle" if all of its dimensions are roughly equal. Thus, particulate-reinforced composites include those reinforced by spheres, rods, flakes, and many other shapes of roughly equal axes. There are also materials, usually polymers, that contain particles that extend rather than reinforce the material. These are generally referred to as "filled" systems. Because filler particles are included for the purpose of cost reduction rather than reinforcement, these composites are not generally considered to be particulate composites. Nonetheless, in some cases the filler will also reinforce the matrix material. The same may be true for particles added for nonstructural purposes such as fire resistance, control of shrinkage, and increased thermal conductivity.

Fiber-reinforced composites contain reinforcements having lengths much greater than their cross-sectional dimensions. Such a composite is considered to be a discontinuous fiber or short fiber composite if its properties vary with fiber length. On the other hand, when the length of the fiber is such that any further increase in length does not, for example, further increase the elastic modulus of the composite, the composite is considered to be continuous fiber reinforced. Most continuous fiber (or continuous filament) composites, in fact, contain fibers that are comparable in length to the overall dimensions of the composite part.

Laminar composites are those composed of two (or more) layers with two of their dimensions being much larger than their third. Complicating the definition of a composite as having both continuous and discontinuous phases is the fact that in a laminar composite, neither of these phases may be regarded as truly continuous in three dimensions.

With some few specific exceptions, only "high-performance" composites will be considered in this Volume. These are composites that have superior performance compared to conventional structural materials such as steel and aluminum alloys. Thus, the emphasis will be on continuous fiber reinforced composites, although the principles will often be applicable to other types of composites as well. Furthermore, continuous fiber reinforced composites will generally be referred to as simply fiber-reinforced composites, and, in some cases, as merely fiber composites or composites. In addition, composites with organic (resin) matrices will be emphasized throughout this Volume, both because such composites are the most commonly used and because of the significant dissimilarities between organic-matrix composites and those made with metal, ceramic, and carbon matrices.

Composite materials were developed because no single, homogeneous structural material could be found that had all of the desired attributes for a given application. Fiber-reinforced composites were developed in response to demands of the aerospace community, which is under constant pressure for materials development in order to achieve improved performance. Aluminum alloys, which provide high strength and fairly high stiffness at low weight, have provided good performance and have been the main materials used in aircraft structures over the years. However, both corrosion and fatigue in aluminum alloys have produced problems that have been very costly to remedy. World War II promoted a need for materials with improved structural properties. In response, fiber-reinforced composites were developed, and by the end of the war, fiberglass-reinforced plastics had been used successfully in filament-wound rocket motors and in various other structural applications. These materials were put into broader use in the 1950s, and initially seemed to be the only viable approach available for the elimination of corrosion and crack formation in high-performance structures. Although more recent developments in metallic materials have led to some solutions to these problems, fiber-reinforced composites still provide other substantial benefits to designers and manufacturers.

Inexpensive fiberglass composites are used today in a wide variety of applications, from consumer products, such as the fiberglass boat shown in Fig. 1, to aerospace. More advanced fiber-reinforced composites, however, have been limited in their commercial use because of high materials cost, lack of widely distributed property and processing data bases, and the absence of rapid and efficient manufacturing techniques. However, fiber-reinforced composites have been developed and widely applied in aerospace applications to satisfy requirements for enhanced performance and reduced maintenance costs. In large commercial aircraft they have found application because of the weight considerations that were highlighted by the energy crisis of the 1970s.

Fiber composites offer many superior properties. Almost all high-strength/high-stiffness materials fail because of the propagation of flaws. A fiber of such a material is inherently stronger than the bulk form because the size of a flaw is limited by the small diameter of the fiber. In addition, if equal volumes of fibrous and bulk material are compared, it is found that even if a flaw does produce failure in a fiber, it will not propagate to fail the entire assemblage of fibers, as would happen in the bulk material. Furthermore, preferred orientation may be used (as in aramid and carbon fibers) to increase the lengthwise modulus, and perhaps strength, well above isotropic values. When this material is also lightweight, there is a tremendous potential

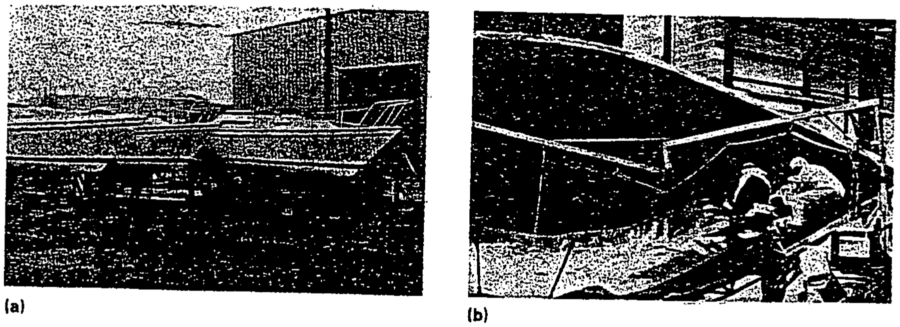

Fig. 1 (a) Eight-meter (27-ft) sailing sloop representing a fiberglass mat and roving reinforced resin matrix composite. (b) Fabrication of fiberglass hull by lay-up process. Courtesy of Pearson Yachts Corporation

advantage in strength-to-weight and/or stiffness-to-weight ratios over conventional materials. These desirable fiber properties can be converted to practical application when the fibers are embedded in a matrix that binds them together, transfers load to and between the fibers, and protects them from environments and handling. In addition, fiber-reinforced composites are ideally suited to anisotropic loading situations where weight is critical. The high strengths and moduli of these composites can be tailored to the high load direction(s), with little material wasted on needless reinforcement.

Plots of the specific tensile strength (strength/density) versus specific tensile modulus (modulus/density) for various fiber-reinforced composites are shown in Fig. 2(a) and 2(b); the former gives fiber direction values for 65 vol% unidirectional composites, while the latter shows in-plane data for quasi-isotropic composites, in which the reinforcement is approximately isotropic in-plane. In both cases, the strengths and moduli are based on intrinsic fiber values, as taken from manufacturers' literature. These values for fibers will produce good estimates of composite modulus values, but may be off by a considerable amount—sometimes a factor of two or more—for strengths. (This discrepancy between the strength value estimated from fiber strengths and the actual value for the composite is due to factors such as processing damage, increased statistical likelihood of flaws in a larger part, and incorrect fiber orientation.) In spite of the approximate nature of the strength data, the plots offer an excellent explanation for the wide use of fiber-reinforced composites. Compared to conventional structural materials, the improvements in specific properties can be tremendous.

Glass fiber reinforced organic matrix composites are the most familiar and widely used, and have had extensive application in industrial, consumer, military (Fig. 3), and aerospace markets. Carbon fiber reinforced resin matrix composites are by far the most commonly applied advanced (nonfiberglass) composites for a number of reasons. They offer extremely high specific properties, high quality materials that are readily available, reproducible material forms, increasingly favorable cost projections, and comparative ease of manufacture. Composites reinforced with aramid, other organics, and boron fibers, and with silicon-carbide, alumina, and other ceramic fibers are also used.

Recent technology has provided a variety of reinforcing fibers and matrices that can be combined to form composites having a wide range of very exceptional properties. In many instances the sheer number of available material combinations can make selection of materials for evaluation a difficult and almost overwhelming task. In addition, once a material is selected, the choice of an optimal fabrication process can be very complex. Simplifying these tasks is one of the purposes of this Volume.

This introduction will briefly outline the basic materials, design considerations, material forms, and fabrication processes used in the production of high-performance continuous fi-

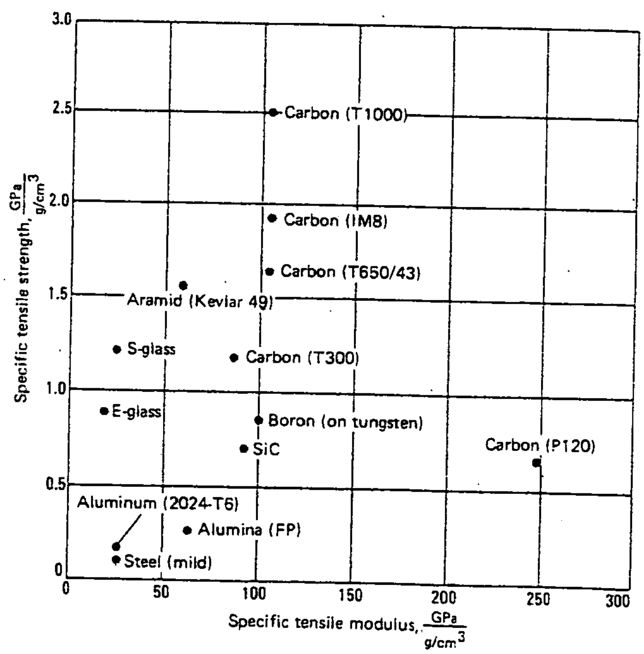

Fig. 2(a) Specific tensile strength (strength-to-density ratio) versus specific tensile modulus (modulus-to-density ratio) for various commercially available 65 vol% unidirectional epoxy-matrix composites and for steel and aluminum. Strength and modulus are based on fiber values. Note that T1000 carbon fiber is currently available only in limited quantities.

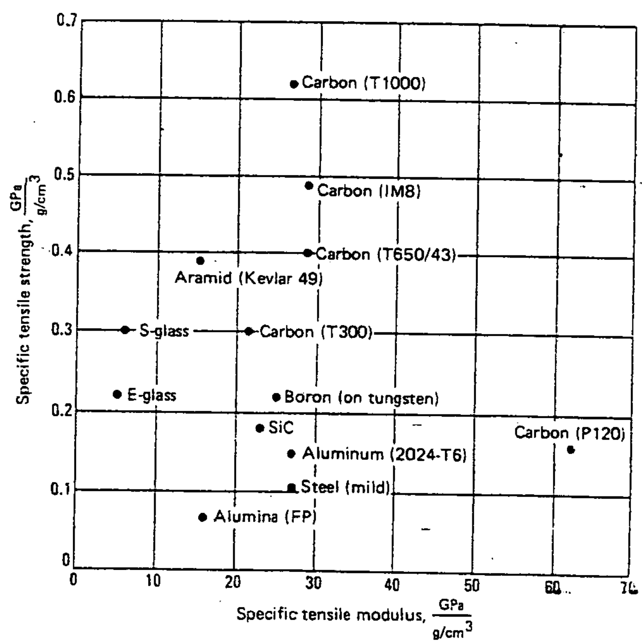

Fig. 2(b) Specific tensile strength (strength-to-density ratio) versus specific tensile modulus (modulus-to-density ratio) for various commercially available 65 vol% quasi-isotropic epoxy matrix composites, and for steel and aluminum. Strength and modulus are based on fiber values. Note that T1000 carbon fiber is currently available only in limited quantities.